LONGITUDINAL RECOVERY OF A STREAM AFFECTED BY A SKI AREA DEVELOPMENT

by

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Final Report

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Longitudinal Recovery of a Stream Affected by a Ski Area Development

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by

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ABSTRACT

Past studies of the Rio en Medio have demonstrated significant alterations of water quality and communities of invertebrates below the Santa Fe Ski Area. The present study was undertaken to determine how far downstream the effects of the ski area extend.

The concentration of every major nutrient except $SO_4^=$ was found to increase below the ski area and the only mechanism for recovery seemed to be dilution by downstream tributaries. Increased sediment loads below the ski area were also recorded. Peaks of sediment transport were associated with snow melt and summer rains. Much of the increased sediment below the ski area appeared to settle out in the upper reaches of the Rio en Medio.

Composition and diversity of stream insects appeared to be little affected. However numbers and biomass of invertebrates were significantly reduced below the ski area. These reductions were attributed to the effects of increased sediment load. Some recovery of invertebrate production was recorded at distances of 500m to 2000 m below the most heavily impacted site.

Introduction

Significant alterations of water quality below the Santa Fe Ski Area have been documented (Gosz 1975, 1977a, 1977b). The increased levels of sediment, major nutrients, and heavy metals that have been reported for the Rio en Medio, the stream and draining the ski area, were primarily the result of road salting and construction activities. The majority of past water quality studies on the Rio en Medio have been limited to reaches immediately above and below the ski area and it is not known how far downstream the effects of the ski area extend.

A study of the Rio en Medio has demonstrated major shifts in the structure of communities of invertebrates below the ski area (Molles 1978). Several factors may be involved in these community changes. Sedimentation has created a predominately sand bottom in some sections of the stream. Such areas have been shown to support less biomass of invertebrates compared to stony bottoms (Pennak and Van Gerpen 1947, Hynes 1970, Ward 1975). Obviously if increases in the concentrations of nutrients and heavy metals below the ski area reach toxic levels invertebrates would be affected. However, even small changes in the concentration of inorganic ions have been shown to determine the outcome of competitive interactions between some aquatic organisms (Patrick et al. 1969, Patrick 1978).

Changes in stream faunas along elevational gradients are well-described (see Macan 1961, Hynes 1970, Allan 1975, for reviews). This backlog of information provides qualitative predictions concerning the structure of invertebrate communities in undisturbed streams and is useful for comparison with the results of the present study. For example, from past studies one would predict that production of invertebrates

would increase downstream from the upper reaches of the Rio en Medio (Gaufin 1959, Mecom 1972, Pennak 1977). However, the Rio en Medio immediately below the Santa Fe ski area has been shown to be an area of reduced production (Molles 1978).

As with studies of water quality, studies of the fauna of the Rio en Medio have been performed only immediately below the ski area and it is not known how far downstream impacts extend. Such information seems critical to an evaluation of the overall effect of the ski area on adjacent ecosystems.

Objectives

The overall objective of this study was to answer the question of how far downstream the effects of the ski area extend. Specifically we attempted to: (1) monitor water quality at a number of distances below the ski area in an attempt to quantify the rate of recovery; (2) quantify longitudinal recovery of stream invertebrate communities perturbed by water quality changes resulting from a ski area development.

In addition we hoped to evaluate the influences of different aspects of water quality on stream invertebrates because of differential recovery rates. The movement of sediment with distance should be very different from the movement of soluble nutrients and the stream invertebrate community may react accordingly.

Study Area

The study area is the Santa Fe Ski Basin located about 15 km northeast of Santa Fe, New Mexico in the Sangre de Cristo Mountains. The ski basin is located at the headwaters of the Rio en Medio, a perennial stream. The vegetation of the ski basin is primarily Engelmann spruce (*Picea engelmanni* (Parry)) and corkbark fir (*Abies lasiocarpa* var. arizonica (Meriam) Lemm.) with small areas of aspen (*Populus tremuloides* Michx.) scattered throughout the basin below 3355. Alpine tundra occurs from 3660 m to the top of the basin at 3762 m. The soil of the ski basin is primarily a Nambe cobbly loam (Dystric Cryocrept, loamy-skeletal, mixed) with moderate to high infiltration capacity. The soils are relatively deep (> 1.5 m) and the permeability of the least previous horizon is 1.6 to 5.1 cm/hr (Carleton, et al. 1972). Precipitation during the study period was relatively low (weighted average of 71 cm for the basin) and discharge about 26 cm. Stream volumes did not exceed 2 cfs during the study period. Evapotranspiration amounted to 63.5% of precipitation.

A short distance below the upper sampling location (above-road) the stream is diverted by a gate dam and underground pipe into Windsor Creek which rejoins the Rio en Medio about 500 m below the road (see Fig. 1).

Methods

Water quality parameters studied were 1) suspended solids, 2) conductivity, and 3) concentrations of Ca^{++}, Mg^{++}, K^{+}, Cl^{-}, $SO_4^{=}$, NO_3^{-}, and NH_4^{+}. Three samples were collected from each collection site at weekly intervals. Samples were collected in a 1 liter, unacidified polyethylene bottle, an acid washed, 500 ml polyethylene bottle which was pretreated with acid for sample preservation, and an acid washed, 500 ml polyethylene bottle without acid added. Suspended solids were determined gravimetrically after filtering the contents of the 1 liter bottle. Conductivity was measured on the unacidified sample by a YSI model conductivity meter. Metallic cations were analyzed on the acidified sample by atomic absorption spectrophotometry using flame methodology. Lanthanum chloride was added for analyses of Ca^{++} and Mg^{++} to prevent interferences. The anions and NH_4^{+} were analyzed by standard methods for a Technicon Autoanalyzer II system.

Stream invertebrates were sampled at five sites on the Rio en Medio: above the ski area, 200 m below the road, 700 m below the road, 1200 m below the road, and 2200 m below the road (Fig. 1). Twelve Surber samples (.093 m^2) were taken at each site in May and October of 1977. Samples were taken in midstream at intervals of 5 m beginning 55 m below each study site.

Samples, all of which contained a considerable amount of debris and water, were fixed in 95% ethanol in the field. Invertebrates were transferred to 70% ethanol at the time of sorting. Final sorting, identification, counting, and weighing of invertebrates were done in the laboratory. Dry weights were taken by drying specimens with a Mettler LP12 infrared drying unit, cooling them in a dessicator and weighing on a Mettler H54AR semi-micro balance (precision = ± .01 mg).

Species diversity was calculated using the Shannon-Wiener diversity index (Shannon and Weaver 1949), $H' = -\Sigma\ p_i \ln p_i$. In this index, the proportion of a sample represented by the i^{th} species, p_i, is generally calculated on the basis of relative number of individuals. The assumption is that all species are approximately the same size. However, in the present study, there were great differences in size between species and between instars of the same species. In such instances, biomass is a more meaningful index of relative importance of species (Whittaker 1975, Pianka 1976). Therefore, dry weights were used to calculate the relative proportions of species in a collection, i.e., $p_i = \frac{w_i}{W'}$, w_i = dry weight of the i^{th} species and W = total dry weight of the collection.

All Surber samples for a given date and study site were pooled for calculations of species diversity. In these calculations, only insects of the orders Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera were included. All members of these orders could be identified at least to "morpho-species". Other groups were excluded because of taxonomic difficulties.

Because the data did not meet the assumptions of parametric tests statistical comparisons of numbers and biomass of invertebrates were made using the Kruskal-Wallis test with a procedure for multiple comparisons (Zar 1974).

Results

An analysis of water samples above and below the road subject to road salting demonstrated an increase in every nutrient studied except $SO_4^{=}$ (Table 1). This has been reported for other studies on this stream (Gosz 1975a, 1977a, 1977b), and is the result of significant additions of NaCl to the stream water plus the removal of other elements from the soil by mass action of Na^+ and Cl^-. The largest change in water quality occurred immediately below the road (200 m) with much smaller changes (increases and decreases) occurring at other distances. At distances from 800 to 2200 m below the road, concentrations and conductivity were not significantly different ($p > .05$). The 200 and 400 m distances also were statistically similar ($p > .05$) although Na^+ and Cl^- appear to have decreased at the 400 m distance. All concentrations significantly decreased between 400 and 800 m as a result of the input of water from Windsor Creek (see Fig. 1). Although the Windsor was influenced by road salt (to be discussed later), concentrations were relatively low (except $SO_4^{=}$) and caused a dilution of the soluble salts in the Rio en Medio. The reason why $SO_4^{=}$ demonstrates an inverse pattern to other cations and anions is not known at this time.

Other studies of water quality over an elevation gradient have demonstrated a predictable pattern (Gosz 1975b, 1978a). Cations (e.g. Mg^{++}) increased in concentration with decreasing elevations as a result of higher concentrations in tributaries at lower elevations and evaporation of stream water. It is important to ascertain how the water quality of the Rio en Medio corresponds to this natural pattern. The Santa Fe River was chosen as the control because of its undistubed condition, and similarity of vegetation, geology, and elevation with the Rio

en Medio watershed. Table 2 shows concentrations of 4 cations and conductivity along a section of the stream which corresponds to the Rio en Medio. Although Ca^{++} was somewhat variable, all tended to increase with increasing distance downstream. Comparing tables 1 and 2 it can be shown that the upper elevations of the two streams had similar concentrations, however, the addition of road salt caused a large increase in soluble salts in the Rio en Medio. Although concentrations seem to have stabilized between 800 and 2200 m on the Rio en Medio they were substantially higher than concentrations on the Santa Fe River.

While the yearly average concentrations are useful in summarizing general trends in water quality over stream distance they mask important seasonal differences. Road salt, although applied over a number of winter months, generally leaves the watershed during the shorter period of snow melt. Very high concentrations may occur during these short periods which may be more important than the trends indicated by yearly average concentrations.

Calcium and Magnesium

Calcium and Mg^{++} demonstrated very similar trends, therefore, only Ca^{++} is shown (Fig. 2). Several distinct patterns can be seen in this figure. First, distances 800 to 2200 m had very similar concentrations which supports the analysis of the yearly average concentrations. There is no indication that a substantial recovery was made to natural water quality conditions. Second, the 400 m distance differed greatly from the greater distances and demonstrated higher values throughout most of the study period. Thirdly, there was an interval early in the spring snow melt period when the 400 m distance had markedly lower concentrations than the 800 to 2200 m distances. The reason for the second and

third patterns was the input of Windsor Creek to the Rio en Medio. Figure 3 shows Ca^{++} concentrations for Windsor, Rio en Medio above the road and 200 m below the road. As a result of road salt, the below road Ca^{++} concentrations were always greater than the above road levels. Windsor Creek also was influenced by road salt (see Fig. 1), however, the topography is such that snow melt occurred along the road area of the Windsor earlier than that of the Rio en Medio.

This caused the Rio en Medio below the confluence of the Windsor to have relatively high concentrations. In May the below-road area of the Rio en Medio had the highest concentrations and the Windsor acted to dilute those concentrations below its confluence. The reason the Windsor, in general, had lower solute concentrations was due to a smaller input of road salt (less road contact) and the input of water from the upper Rio en Medio via the stream diversion (see Fig. 1).

The reason for the relatively high concentrations at the 200 and 400 m distances throughout the summer months seems to be a result of the low snow fall that particular year (Gosz 1977a). With a low snow pack the road salt, and other elements which it removes, was not completely flushed out during snow melt. Summer rains continued to remove this material causing a pattern quite different from one during a year with abundant snow (Gosz 1977a).

Potassium

This element was found in lower concentrations than Ca^{++}, however, it demonstrated a pattern similar to that of Ca^{++} and Mg^{++} (Fig. 4,5). The influence of the Windsor on the lower distances of the Rio en Medio was not as pronounced as for Ca^{++}.

Sodium

Road salt was the source of the high concentrations of this element (Fig. 6,7) and the patterns were quite similar to those of Ca^{++}, Mg^{++}, and K^{+}. The essentially identical patterns from 800 to 2200 m on the Rio en Medio indicate that dilution by tributaries such as the Windsor was the only method of recovery. The similarity of patterns between Na^{+} and other elements not found in road salt (Ca^{++}, Mg^{++}, K^{+}) supports the conclusion that road salt addition causes the loss of other nutrients from roadside areas (Gosz 1977a).

Chloride

This element is virtually the only anion added by road salting and it demonstrated essentially the same patterns as the above mentioned cations (Fig. 8,9). Concentrations of Cl^{-} during the study period were markedly lower than reported for this area during other years (Gosz 1977a). This was due primarily to the low snow pack which did not completely flush Cl^{-} during snow melt and perhaps less road salt application.

Nitrogen

This very important element had patterns distinctly different from other cations and ions. For NH_4-N there essentially was no pattern (Fig. 10,11). Other than an occasional unexplained high concentration there was little difference for any of the sampling points. The most logical explanation is that this compound has a relatively low concentration in the soil and the addition of road salt should influence it less than other more abundant elements. This is supported by the pattern of K^{+}. Its relatively low concentration in soil relative to Ca^{++}, Mg^{++} and Na^{+} caused a great reduction in the magnitude of the difference

between sites. Another possibility is that NH_4^+ is an important biological nutrient and excesses may be quickly removed by the demands of terrestrial and aquatic organisms.

Nitrate N showed a pronounced seasonal pattern at all sampling sites of high concentrations during the cooler months and low concentrations during the warm months (Fig. 12,13). This has been found by other investigators and has been suggested to be a result of biological uptake (Gosz 1978b, Muller and Bormann 1977). The below-road stream appeared to have slightly higher concentrations than above the road which suggests that this nutrient may have been affected by the road salting activity. There are a number of other factors which could affect NO_3-N levels in stream water, however (Gosz 1978b). The greater distances (800 to 2200 m) had essentially identical concentrations.

Sediment

One of our original questions was whether the impact on stream organisms was more a result of sediment than soluble salts. We expected that sediment would be transported differently than the soluble salts, therefore, it would be possible to separate the two. Figures of suspended sediment concentrations with distance show some important differences from the soluble salts, however, they were not quite what we predicted (Fig. 14,15). There was a pronounced spring peak associated with the inital high discharge during snow melt as well as relatively high levels during the summer rainy season. The summer period is interesting in that the distances 800 to 2200 m had higher concentrations than the 400 m distance (Fig. 14). This was due to high inputs from Windsor Creek (Fig. 15). The reason for these high levels in Windsor was that significant construction activity was occurring in the skiing

area and along the road paralleling the stream diversion. These activities, which involved soil disturbance, caused runoff water with high sediment levels to be diverted into Windsor Creek and subsequently to the lower Rio en Medio. While we did not expect this pattern it was distinctly different from those of the soluble salts and may allow us to explain whether benthic invertebrates in our stream are affected by sediment more than soluble salts.

Composition and Diversity of Invertebrates

The ski area development appears to have had little effect on the composition or diversity of stream insects. These results are consistent with the earlier findings of Molles (1978). A total of 32 taxa (species or "morpho-species") were identified during the study (Table 3). Of these species only two were restricted to the above-road collections and both were rare. Five of the thirty-three species collected were confined to below-road sites. However, it has been long known that undisturbed streams harbor species in their lower reaches which are not found upstream (Dodds and Hishaw 1925, Hynes 1970). Therefore, the addition of these species below the ski area cannot be attributed to disturbance.

The composition of insects of the Rio en Medio (Table 3) was strikingly similar to those encountered by Allan (1975) in his thorough study of Cement Creek, Colorado. Allan recorded 27 genera of Ephemeroptera, Plecoptera, Trichoptera and Coleoptera. Of those genera, 21 have been recorded in the present study. Fourteen of the 18 organisms identified to the species level in the present study were also collected by Allan. Since Cement Creek had experienced little human disturbance, Allan's data are valuable for comparison with the results of the present study.

A comparison of numbers of species at a series of elevations on Cement Creek and the Rio en Medio were also surprisingly similar (Fig. 16). The data for the Rio en Medio indicate a plateau in numbers of species averaging around 21 species in May of 1977 and around an average of 22.4 species for the October sample. If these data are shifted to the right, they match well with a plateau in total species counts on Cement Creek extending from 2610 m to 3075 m (average = 20.6 species). In fact, the data points for the Rio en Medio should probably be shifted

to the right for this comparison since it is 3° latitude south of Cement Creek. (The New Mexico site corresponds to a lower elevation site in Colorado, Woodbury, 1954).

It should be noted from Fig. 16 that the number of species reported by Allan for twelve Surber samples was consistently less than his estimates of total species, which included additional qualitative sampling. However, we think that twelve Surber samples resulted in fairly accurate estimates of species density in our study. Examination of nearly 2,000 Ephemeroptera, Plecoptera, Trichoptera and Coleoptera in addition to the 3600 members of these orders collected in twelve Surber samples taken at the above-road site in May yielded only one additional species. The reason underlying the difference between our results and Allan's is unknown. However, the small size of the Rio en Medio is probably a contributing factor.

Human disturbance is generally expected to be associated with a reduction in species diversity. However, species diversity in the present study was lower above the road than at any below-road site during both spring and fall collections (Fig. 17). Highest diversity values were recorded at intermediate elevations during both sampling periods. These patterns deviated more from Allan's results than did patterns of species density. This may have resulted from Allan's use of numbers for the calculation of the evenness component of diversity versus our use of biomass.

Biomass and Numbers

In general the standing crop of invertebrates increases with a decrease in elevation in the streams of the Rocky Mountain Region (Gaufin 1959, Mecom 1972, Pennak 1977). However, in the present study, both total

numbers and total biomass were significantly higher ($p < .05$) above the road than at any below-road site (Tables 4 and 5). The pattern of total numbers between study sites (Fig. 18) indicated no downstream recovery of the benthos within 2 km of the ski area. In contrast, biomass, long considered a better measure of benthic production (Pennak and Van Gerpen 1947), showed some significant recovery in spring 500 m downstream from the 200 m site and in the fall, 2000 m downstream (Fig. 19).

Allan (1975) also found a peak in numbers of stream insects in the upper reaches of Cement Creek. Allan attributed the peak in numbers to the absence of trout at high elevations. However, in the Rio en Medio, trout were present in low densities throughout the section studied.

The majority of the invertebrates collected at all sites were insects of the Orders Ephemeroptera, Plecoptera, Coleoptera, Trichoptera, and Diptera. These orders formed 91% to 99% of total numbers at study sites and from 77% to 95% of the biomass. Nematodes, Oligochaetes and Turbellarians comprised the remainder of the biomass and numbers.

There were pronounced differences between groups of invertebrates in their distributions of biomass and numbers among study sites. Orders of insects showing consistent significant reductions in biomass and numbers at all study sites below the ski area ($p < .05$) were Ephemeroptera, Coleoptera, Diptera, and Turbellaria. These groups were also found to be the most heavily affected in an earlier study of the impact of road salting on stream fauna (Molles 1977).

Groups showing little or no differences in numbers or biomass between study sites were Plecoptera and Oligochaetes. Plecopteran numbers and biomass were similar at all sites during May collections and while significant increases ($p < .05$) in Plecopteran numbers were detected at

all below-road sites in October, Plecopteran biomass was not significantly higher below the road ($p > .05$). Numbers and biomass of Oligochaetes were similar at all sites. This is a departure from the results of an earlier study of the Rio en Medio (Molles 1978) which showed a significant increase in biomass of Oligochaetes below the road. However, while the absolute biomass of Oligochaetes did not increase below the road, the percentage of the total biomass represented by Oligochaetes did increase.

Trichoptera and Nematoda were the only two groups to consistently show higher biomass below the 200 m study site ($p < .05$). Both groups were also more abundant 700 m to 2200 m below the road than at the above-road site.

<u>Relation of Water Quality to Invertebrates</u>

Both suspended sediment and all major ions except $SO_4^{=}$ increased in concentration below the road. Attributing the changes observed in the invertebrates to changes in either water chemistry or suspended sediments would therefore appear difficult. However, changes in these two aspects of water quality can be expected to affect the invertebrate community in different ways. Increases in dissolved substances to the point of toxicity would predictably lead to a reduction in species diversity (Hawkes 1977). Small changes in concentrations of nutrients have been associated with changes in species composition (Patrick et al. 1969, Patrick 1978). However as noted above (see Table 3) neither reductions in diversity nor major shifts in species composition were observed below the road. The major structural changes in communities of invertebrates observed at below-road sites were reductions in numbers and biomass. This strongly suggests sedimentation as the cause (Pennak and Van Gerpen 1947, Gammon

1970, Hynes 1970, Ward 1975).

Partial recovery of invertebrates at stations 700 m, 1000 m and 2000 m is also explainable in terms of sediments. Peaks of suspended sediment loads observed at the 200 m site were an order of magnitude greater than the highest concentrations recorded farther downstream (Figs. 14 and 15), even on the same sampling dates. In addition, peak concentrations of suspended sediments recorded on the Windsor did not extend to the 800 m site. This suggests that sediments were being deposited in the upper reaches of the Rio en Medio. This deposition and retention of fine sediment was enhanced at the 200 m site by log dams. Deposition of sediment in this reach of the Rio en Medio was also observed by Moore et al. (1978) in a study of the distribution of heavy metals in the stream. Movement of this sediment from these upper reaches probably occurs during infrequent high flows associated with storms. Such flows would probably carry sediments beyond the lower study sites and probably all the way down to the Rio Grande Valley at the base of the mountains.

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Table 1. Yearly average element concentrations (mg/l) and conductivity (μmho/cm) in the Rio en Medio above the road and at a number of distances below the road.

Distance (m)	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	NO_3-N	NH_4-N	$SO_4^{=}$	Cl^{-}	Cond.
(above road)	2.86	0.67	0.53	1.89	0.034	0.025	3.04	0.38	31.9
200	5.36	1.15	0.90	4.87	0.094	0.039	2.60	8.61	68.8
400	5.24	1.15	0.85	4.27	0.110	0.040	2.48	7.98	68.4
Windsor	3.83	0.87	0.66	3.16	0.068	0.026	2.87	3.41	45.3
800	4.66	1.07	0.75	3.42	0.077	0.031	2.55	6.28	55.1
1200	4.68	1.08	0.76	3.43	0.073	0.029	2.62	6.24	57.0
2200	4.75	1.08	0.74	3.45	0.062	0.027	2.64	5.63	55.2

Table 2. Element concentrations (mg/l) and conductivity (μmho/cm) in the Santa Fe River on 2 dates. Distances correspond to distances for the Rio en Medio (below a stream elevation of 3105 m)

	June 3					Sept. 2				
Distance (m)	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Cond.	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Cond.
0	3.58	0.71	0.30	1.15	24.7	3.24	0.84	0.31	1.34	31.8
200	2.86	0.77	0.38	1.23	30.5	4.24	0.84	0.40	1.79	36.8
1200	3.06	0.88	0.34	1.36	31.2	3.60	1.04	0.32	1.59	35.5
2590	2.62	0.90	0.36	1.41	32.0	4.05	1.13	0.37	1.72	38.7
6950	9.63	1.23	0.55	1.83	40.2	5.81	1.78	0.64	2.59	66.5

Table 3. Species diversity and composition of Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera collected from the Rio en Medio with a Surber Sampler. Except where indicated otherwise, values are mean dry weights (mg) per .093 m^2.

	Above Road		200 M		700 M		1200 M		2200 M	
	May	Oct.	May	Oct.	May	Oct.	May	Oct.	May	Oct.
EPHEMEROPTERA										
Baetidae										
Baetis bicaudatus	62.476	6.563	13.420	2.046	13.497	2.779	10.742	3.147	9.994	.759
Baetis sp.	-	-	-	-	-	-	-	-	.083	-
Ephemerellidae										
Ephemerella coloradensis	.377	.458	.776	.072	.707	-	.637	.224	.267	.001
E. doddsi	1.067	-	.882	.161	.359	.745	1.309	2.370	1.471	.977
E. inermis	.160	10.782	.002	.462	.050	.097	-	.743	.018	.360
Heptageniidae										
Cinygmula sp.	.285	.066	.198	.088	.135	.056	.317	.071	.124	.020
Epeorus longimanus	.032	.001	.037	-	.001	-	.001	.070	.001	-
Rithrogena sp.	.374	-	-	-	-	.587	1.988	3.455	3.389	2.333
Siphlonuridae										
Ameletus sp.	.322	.092	-	.461	-	.287	.092	-	.510	.080
PLECOPTERA										
Chloroperlidae										
Alloperla sp.	.220	3.998	.560	6.213	.376	1.744	1.945	3.844	2.865	4.223
Nemouridae										
Capnia sp.	-	.007	-	-	-	-	-	-	-	-
Nemoura oregonensis	.133	10.192	.621	3.798	.937	1.575	.396	4.008	.187	8.030
Perlodidae										
Arcynopteryx signata	2.570	-	1.889	.226	4.167	1.469	6.250	2.092	-	.907
Isogenus modestus	.138	.412	.457	.344	.502	.570	.132	.621	.068	.333
Isoperla ebria	.992	.550	.137	.261	.031	.852	-	.291	.057	2.464
Isoperla mormona	-	.045	-	-	-	-	-	.414	-	.001
TRICHOPTERA										
Glossosomatidae										
Glossosoma sp.	-	.003	-	-	-	.538	-	1.864	-	1.485
Hydropsychidae										
Arctopsyche grandis	-	-	-	-	-	-	-	3.461	.627	13.259
Lepidostomatidae										
Lepidostoma sp. 1	.014	-	-	-	-	-	-	-	-	-
Lepidostoma sp. 2	-	-	-	-	-	-	-	-	-	.025
Limnephilidae										
Ecclisomyia sp.	-	-	-	.377	-	.342	-	-	-	-
Neothrema sp.	.015	.637	.022	.102	2.324	4.501	6.940	6.563	1.939	.707
Oligophlebodes sp.	.138	.355	.540	.997	3.093	4.245	1.978	3.564	1.246	1.351
Rhyacophilidae										
Rhyacophila acropodes	-	4.187	2.711	.405	13.054	5.202	21.925	5.527	29.882	9.697
R. alberta	.027	.974	.237	.321	.125	.487	.134	.067	-	-
R. angelita	.144	-	.148	1.188	.200	.321	1.252	.607	1.477	1.074

Table 3. (continued)

	Above Road		200 M		700 M		1200 M		2200 M	
	May	Oct.	May	Oct.	May	Oct.	May	Oct.	May	Oct.
R. hyalinata	.803	.594	.379	1.283	3.555	.089	.613	.178	.462	.084
R. verrula	.037	.025	.067	-	.445	.028	.012	.014	.025	-
Rhyacophila sp.	1.532	1.730	-	3.012	.424	1.407	-	.192	.029	-
COLEOPTERA										
Elmidae										
Heterlimnius corpulentus	4.042	15.141	1.274	.782	.315	.945	.321	.446	.418	.831
Heterlimnius sp.	-	.227	.030	.169	-	-	-	.030	-	-
Narpus concolor	-	-	-	-	-	-	.033	-	-	-
Mean Total Weight	75.901	57.038	24.387	22.768	44.297	28.866	57.017	43.863	55.139	49.001
Number of Species	22	22	20	21	20	22	20	25	22	22
Species Diversity, H'	.860	2.077	1.744	2.360	1.963	2.547	1.936	2.632	1.629	2.211
Species Eveness, J	.278	.672	.582	.775	.655	.824	.646	.818	.527	.715

Table 4. Comparisons of numbers and biomass of invertebrates in the Rio en Medio above and below the road in May 1977. The values listed are means of 12 Surber samples taken at each study site.*

Numbers	Above Road	200 Below Road	700 m	1200 m	2200 m
Ephemeroptera	250.25^{a}	118.00^{b}	103.75^{b}	114.25^{b}	94.92^{b}
Plecoptera	13.17^{a}	54.58^{b}	54.42^{b}	127.25^{c}	82.83^{c}
Trichoptera	9.08^{a}	9.75^{a}	38.58^{b}	48.08^{b}	28.00^{c}
Coleoptera	24.83^{a}	10.42^{b}	2.58^{b}	3.00^{b}	5.08^{b}
Diptera	452.42^{a}	185.16^{b}	144.25^{b}	94.00^{b}	91.25^{b}
Nematoda	--	--	--	--	--
Turbellaria	6.58^{a}	.33^{b}	1.58^{b}	.58^{b}	.08^{b}
Oligochaeta	1.08^{a}	2.83^{a}	2.17^{a}	3.42^{a}	2.58^{a}
Total	757.42^{a}	381.08^{b}	347.33^{b}	390.58^{b}	304.75^{b}
Biomass (mg Dry wt.)					
Ephemeroptera	65.09^{a}	15.31^{b}	14.75^{b}	15.09^{b}	15.86^{b}
Plecoptera	3.75^{a}	3.66^{a}	6.36^{a}	9.47^{a}	3.63^{a}
Trichoptera	2.72^{a}	4.11^{a}	23.22^{b}	32.85^{b}	35.69^{b}
Coleoptera	4.04^{a}	1.30^{b}	.32^{b}	.32^{b}	.42^{b}
Diptera	39.15^{a}	10.01^{b}	17.28^{b}	7.45^{b}	12.87^{b}
Nematoda	--	--	--	--	--
Turbellaria	1.49^{a}	.26^{b}	.52^{b}	.28^{b}	.01^{b}
Oligochaeta	8.39^{a}	5.66^{a}	17.86^{a}	10.69^{a}	3.97^{a}
Total	124.63^{a}	40.31^{b}	80.32^{c}	76.15^{c}	72.44^{c}

*Within each row, means followed by different letters are significantly different ($p < .05$).

Table 5. Comparisons of numbers and biomass of invertebrates in the Rio en Medio above and below the road in October 1977. The values listed are means of 12 Surber samples taken at each study site.*

Numbers	Above Road	200 Below Road	700 m	1200 m	2200 m
Ephemeroptera	465.42[a]	66.75[b]	86.75[b]	117.33[b]	40.25[b]
Plecoptera	106.92[a]	141.25[a]	49.67[a]	105.50[a]	113.42[a]
Trichoptera	32.33[a]	18.83[b]	89.83[c]	95.17[c]	50.75[d]
Coleoptera	94.42[a]	5.08[b]	4.92[b]	3.25[b]	8.92[b]
Diptera	284.83[a]	98.92[b]	127.75[b]	42.25[b]	52.67[b]
Nematoda	.33[a]	.58[a]	2.67[b]	5.83[b]	14.00[b]
Turbellaria	46.17[a]	.42[b]	1.17[b]	.50[b]	.08[b]
Oligochaeta	46.67[a]	1.50[a]	5.08[a]	4.08[a]	2.00[a]
Total	1077.08[a]	333.33[b]	367.83[b]	373.92[b]	282.08[b]
Biomass (mg Dry wt.)					
Ephemeroptera	17.96[a]	3.29[b]	4.55[b]	10.01[c]	4.53[b]
Plecoptera	15.60[a]	11.11[a]	6.21[a]	11.28[a]	15.95[a]
Trichoptera	8.51[a]	7.69[a]	17.16[b]	22.04[b]	27.68[c]
Coleoptera	15.36[a]	.95[b]	.95[b]	.48[b]	.83[b]
Diptera	6.84[a]	4.57[b]	2.45[b]	1.25[b]	20.49[b]
Nematoda	.01[a]	.02[a]	.15[b]	1.24[b]	.65[b]
Turbellaria	15.23[a]	.17[b]	1.05[b]	.69[b]	—[b]
Oligochaeta	1.57[a]	5.43[a]	3.06[a]	.66[a]	11.75[a]
Total	81.09[a]	33.93[b]	35.58[b]	47.65[b]	81.89[c]

*Within each row, means followed by different letters are significantly different ($p < .05$).

Figure 1. Study area showing the Rio en Medio, Windsor Creek and sampling locations. The road, lodges (L), ski lifts, and stream diversion also are indicated.

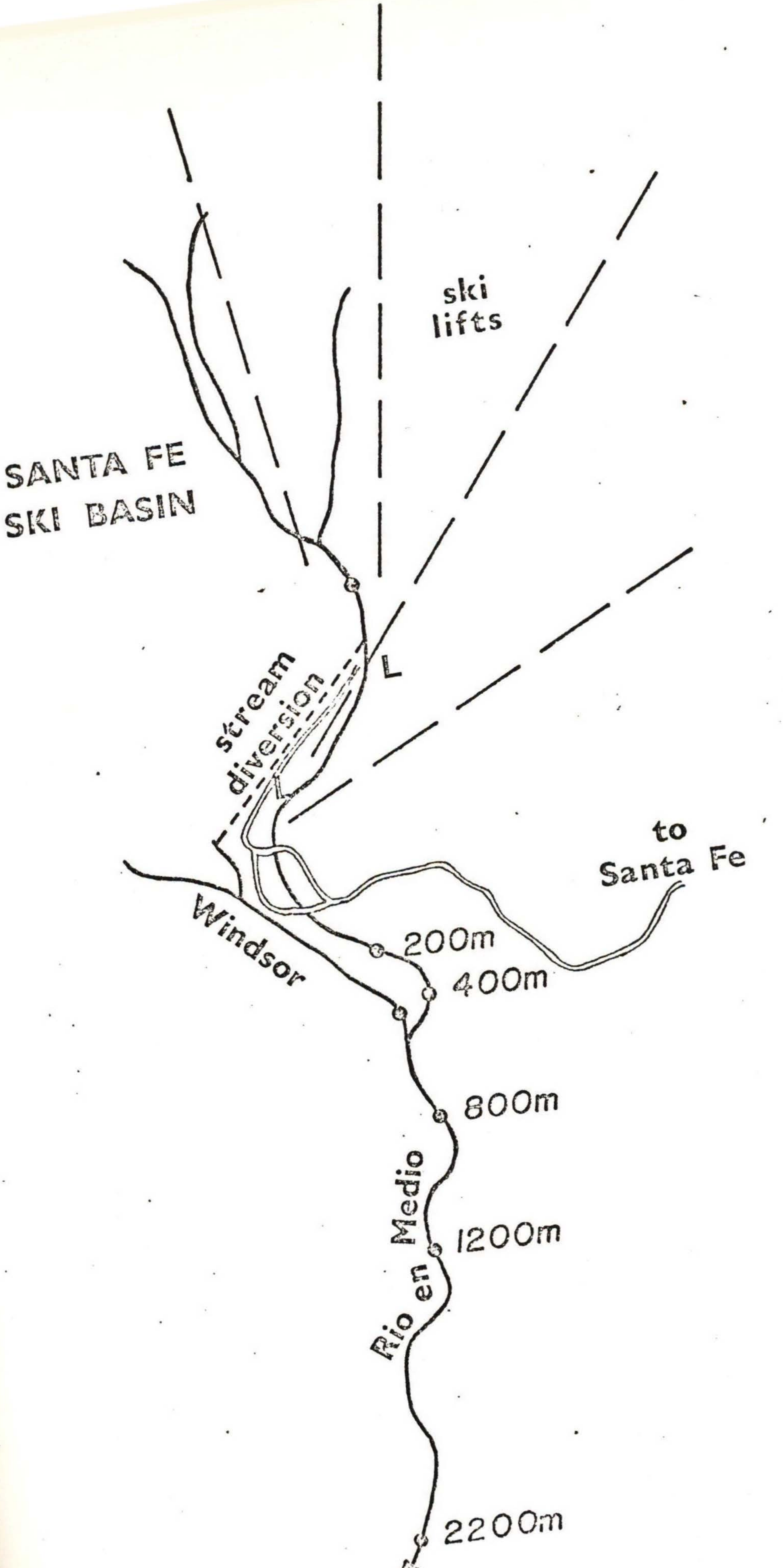
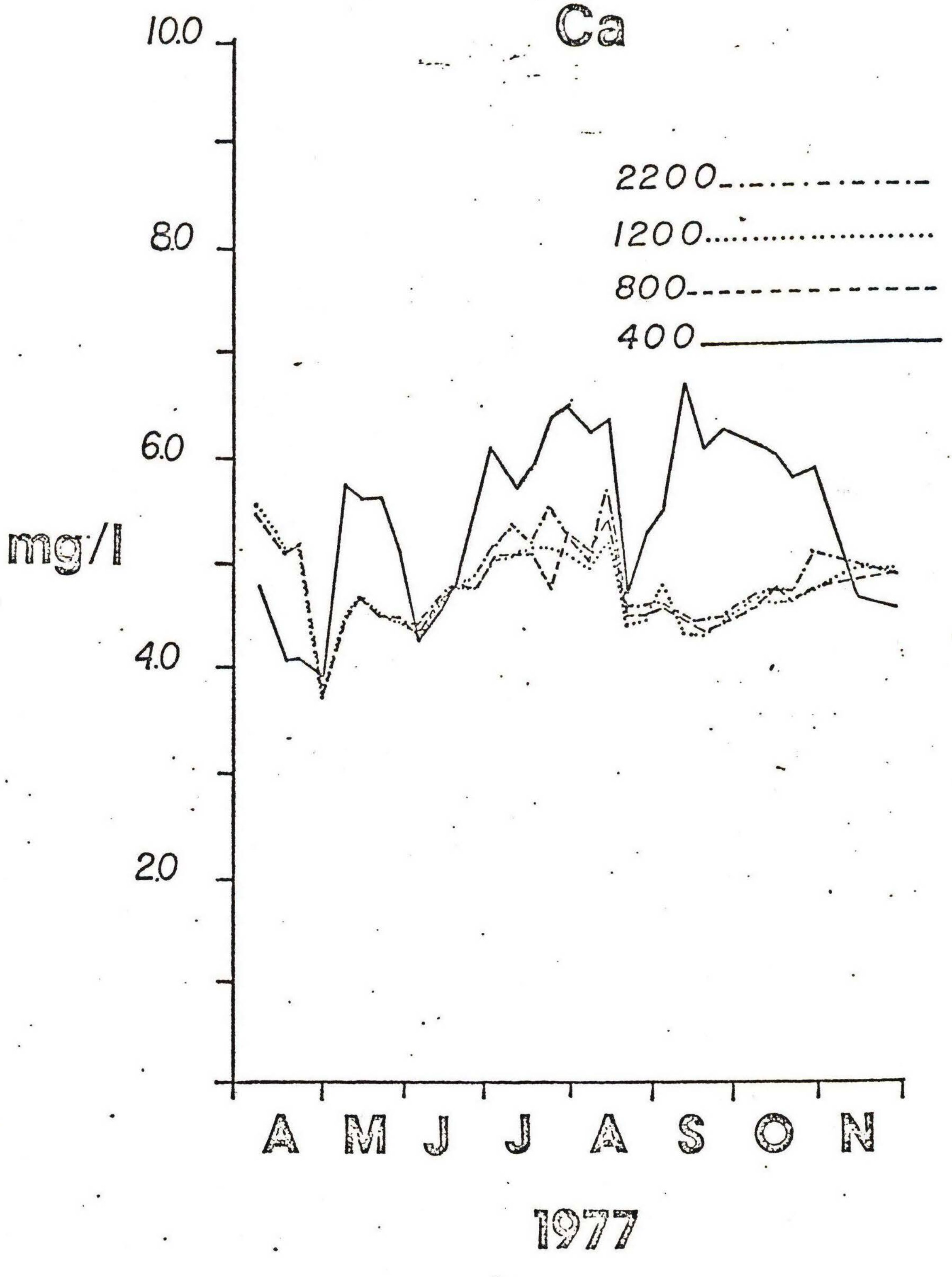

ski
lifts
SANTA FE
SKI BASIN
L
stream
diversion
to
Santa Fe
Windsor
200m
400m
800m
Rio en Medio
1200m
2200m

Figure 2. Calcium concentrations in the Rio en Medio at 400 to 2200 m below the road.



Ca
10.0
8.0
6.0
4.0
2.0
mg/l
2200
1200
800
400
A
M
J
J
A
S
O
N
1977

Figure 3. Calcium concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.

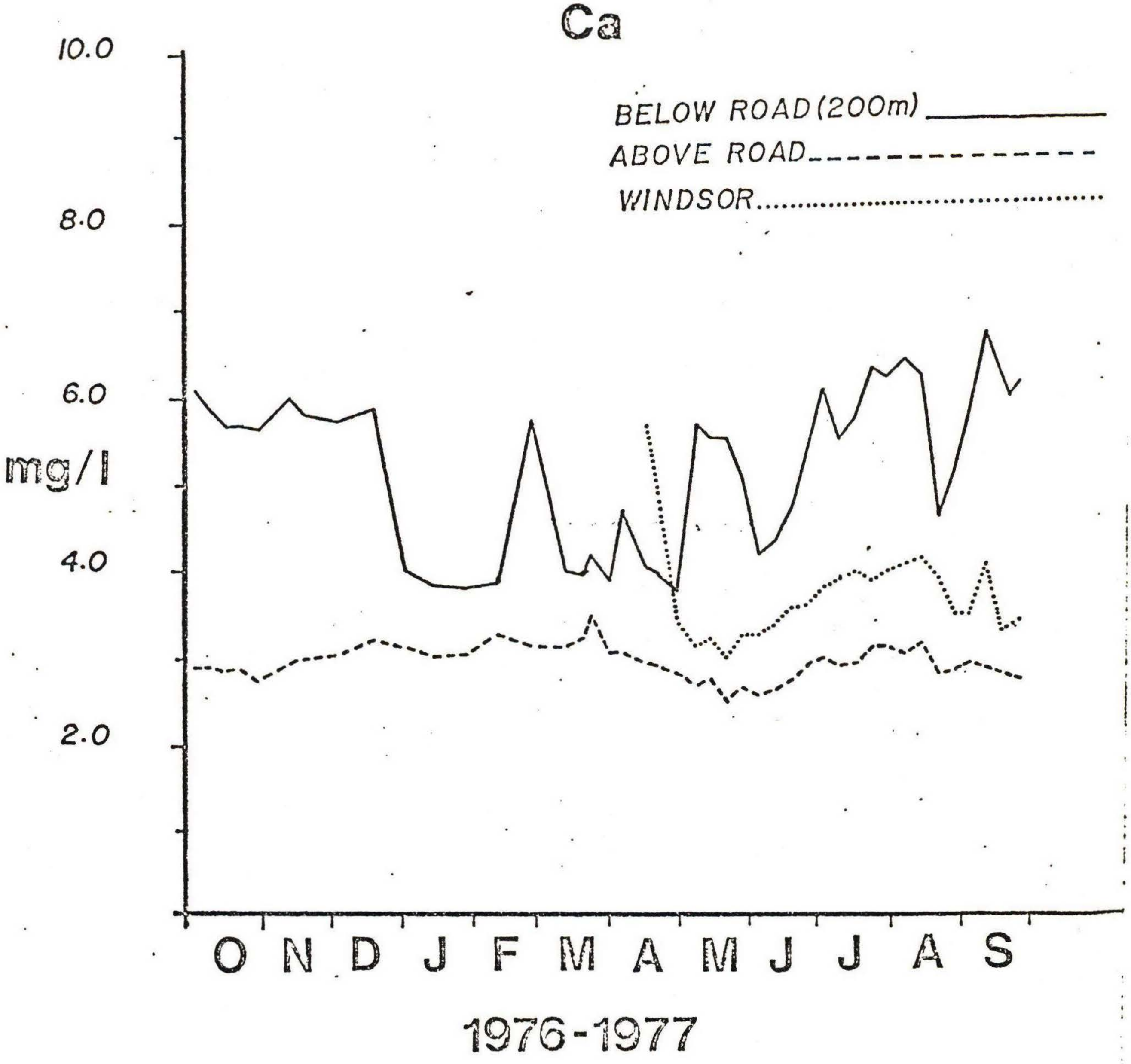

Ca
10.0
8.0
6.0
4.0
2.0
mg/l
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S
1976-1977

Figure 4. Potassium concentrations in the Rio en Medio at 400 to 2200 m below the road.

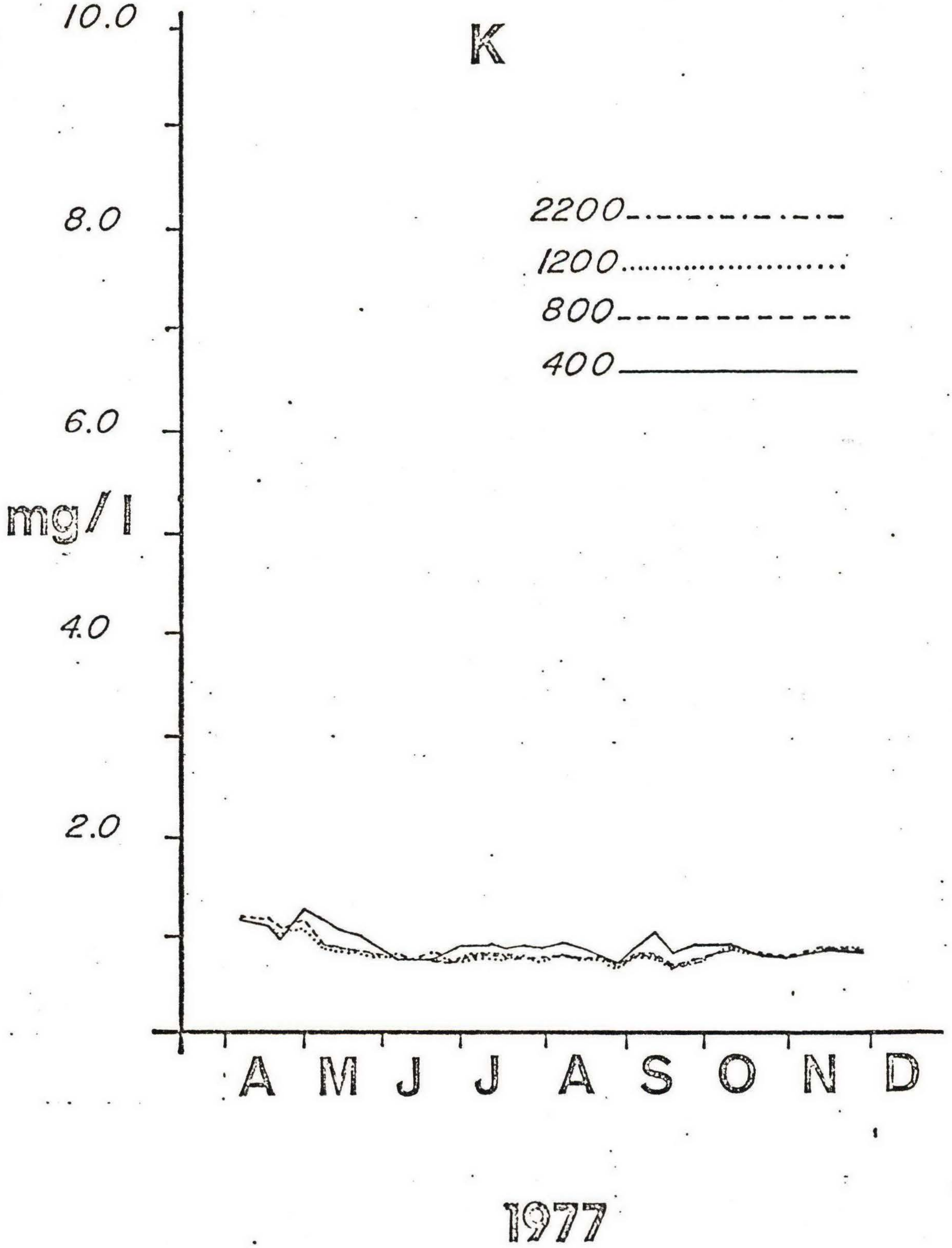
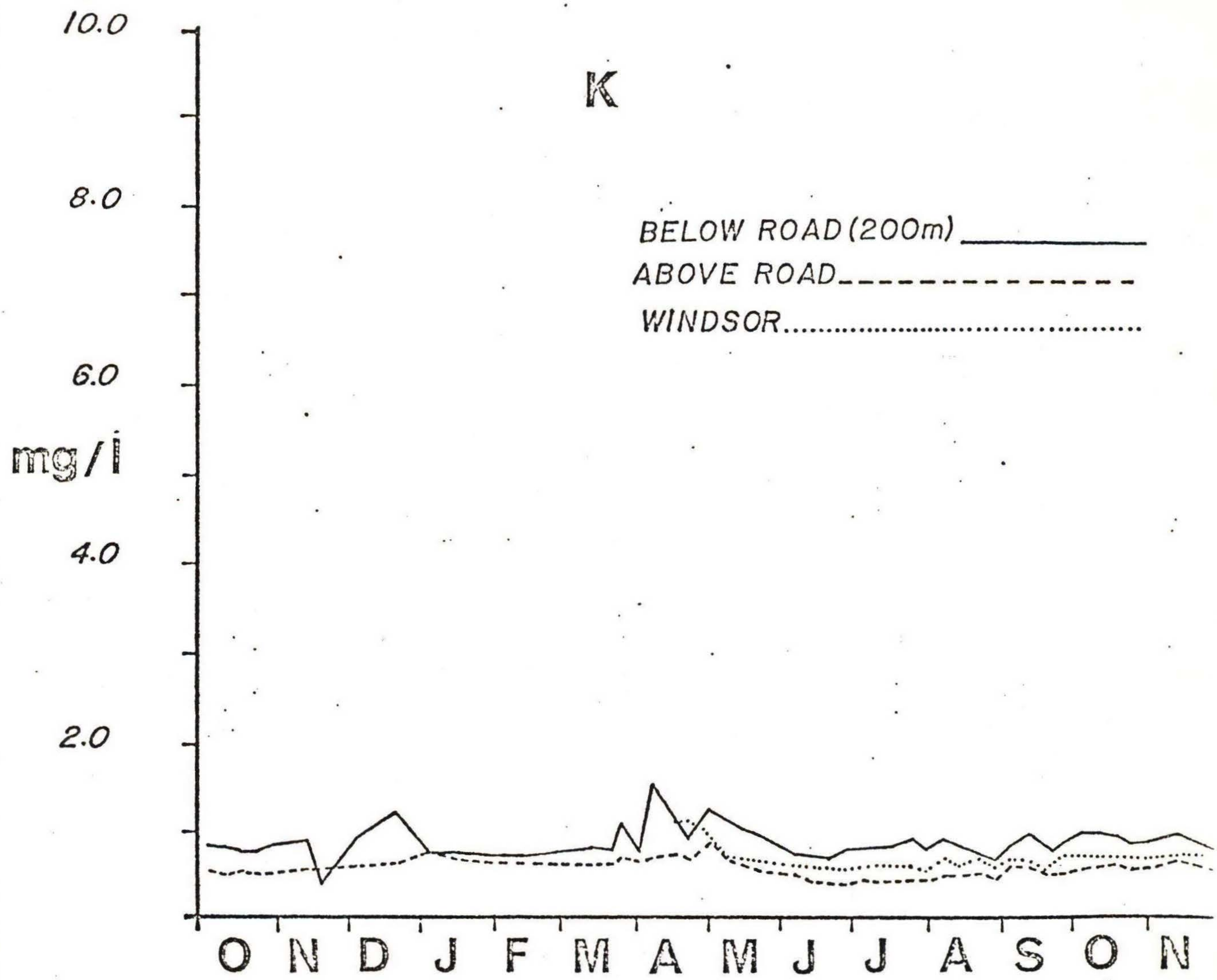

K
10.0
8.0
6.0
4.0
2.0
mg/l
2200
1200
800
400
A
M
J
J
A
S
O
N
D
1977

Figure 5. Potassium concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.



10.0
8.0
6.0
4.0
2.0
mg/l
K
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S O N

1976-1977

Figure 6. Sodium concentrations in the Rio en Medio at 400 to 2200 m below the road.

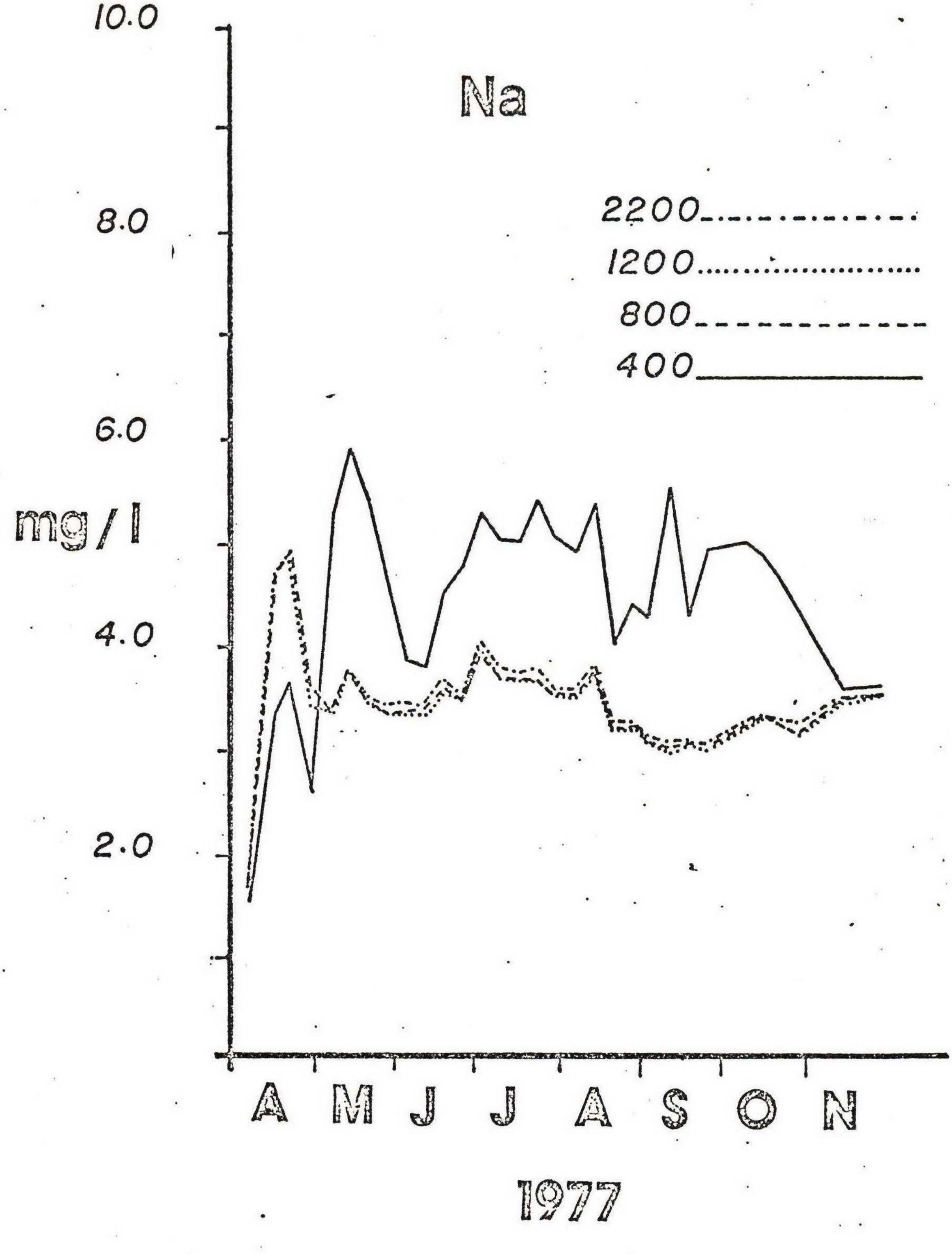

10.0
Na
2200
1200
800
400
8.0
6.0
mg / l
4.0
2.0
A
M
J
J
A
S
O
N
1977

Figure 7. Sodium concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.

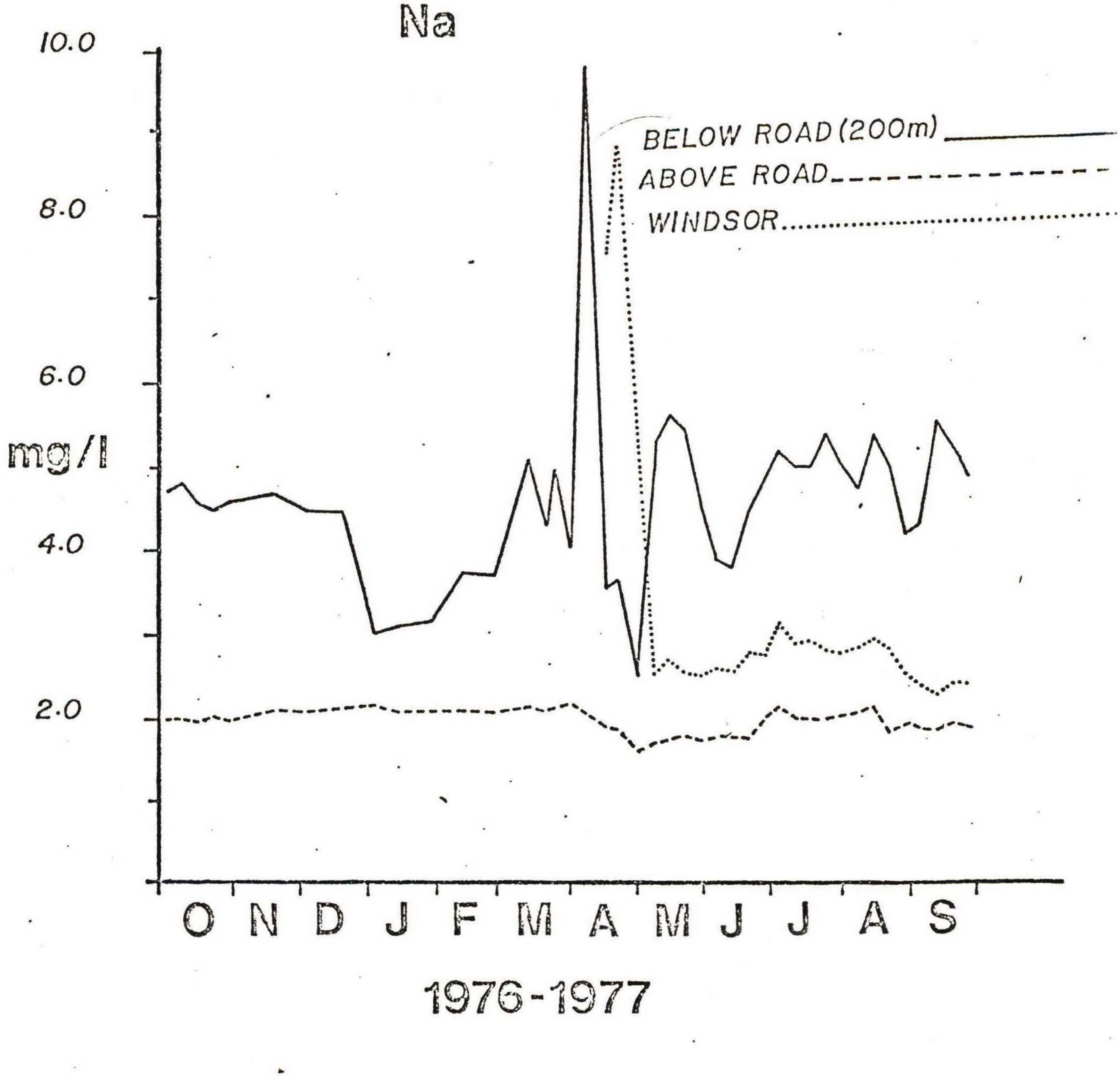
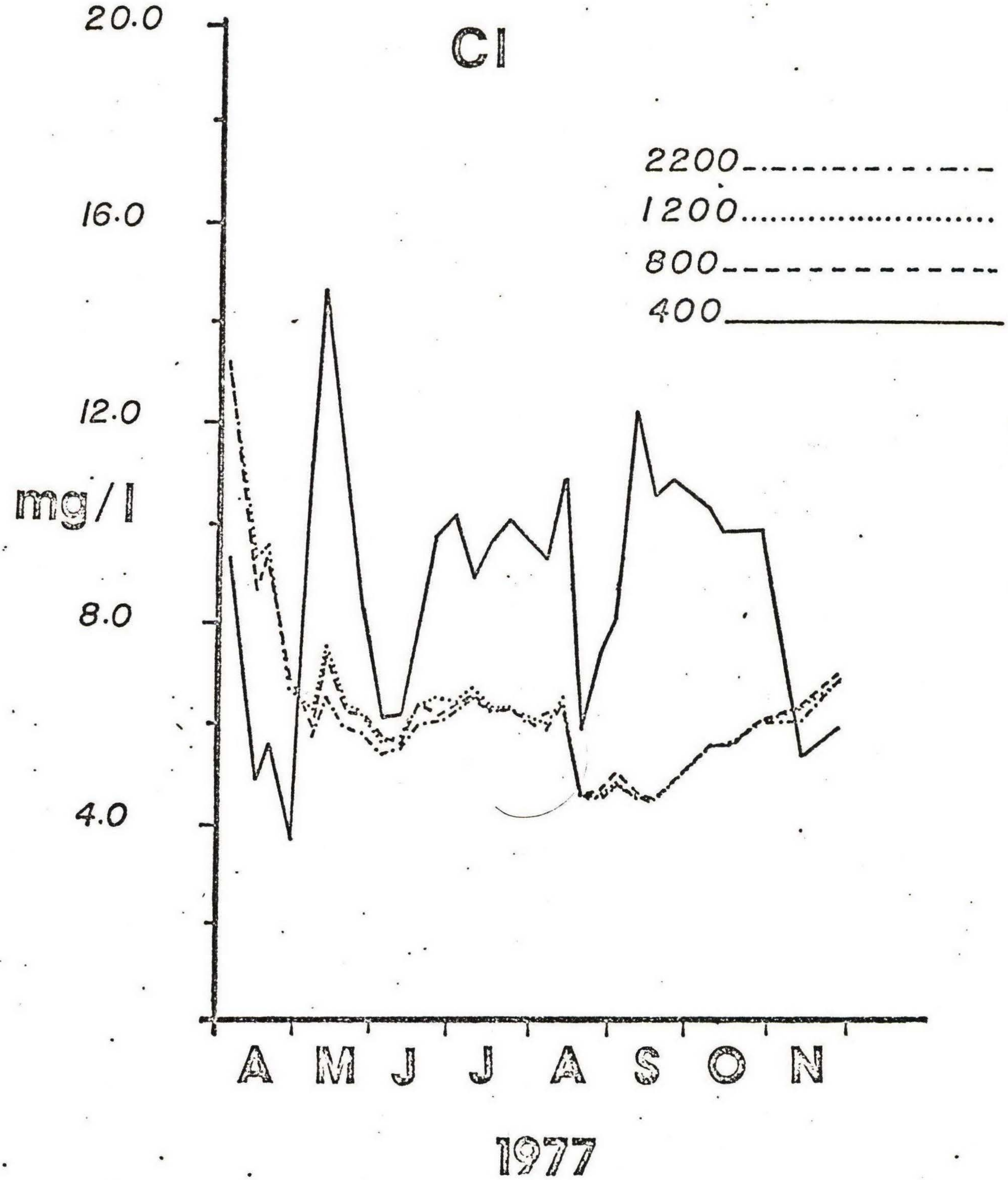

Na
10.0
8.0
6.0
4.0
2.0
mg/l
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S
1976-1977

Figure 8. Chloride concentrations in the Rio en Medio at 400 to 2200 m below the road.



Cl
2200
1200
800
400
20.0
16.0
12.0
8.0
4.0
mg/l
A
M
J
J
A
S
O
N
1977

Figure 9. Chloride concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.

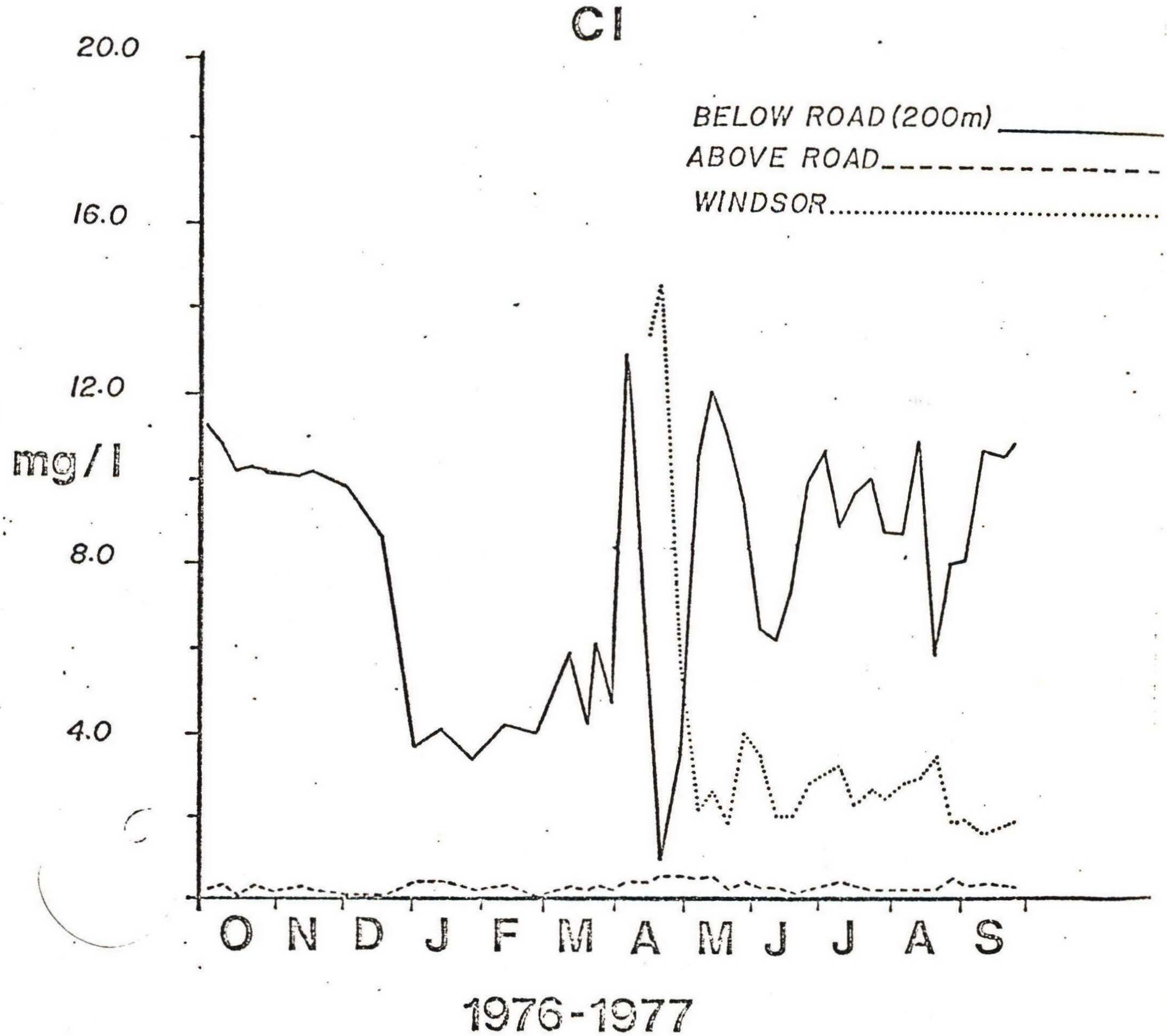
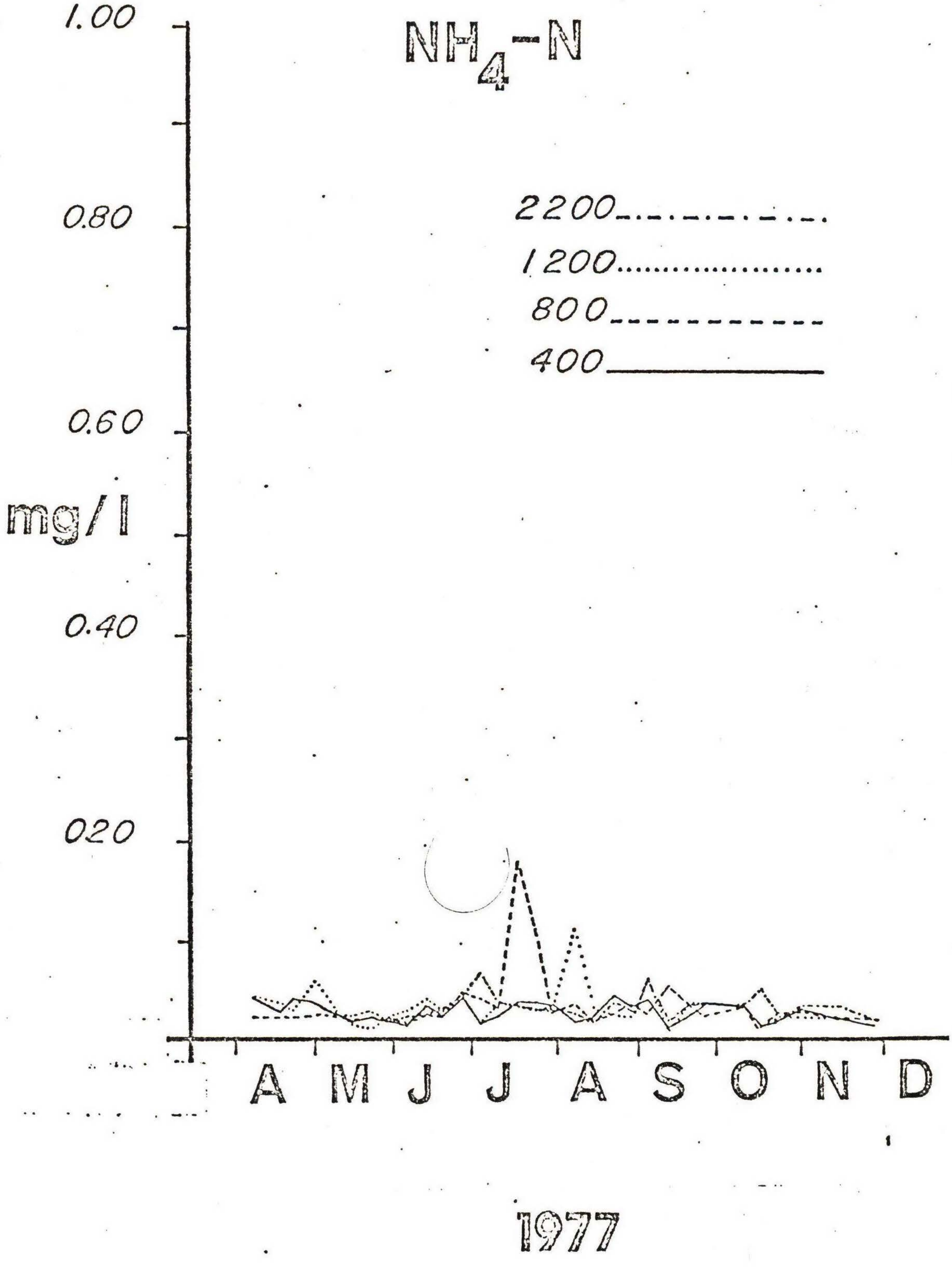

Cl
20.0
16.0
12.0
8.0
4.0
mg/l
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S
1976-1977

Figure 10. Ammonium-Nitrogen concentrations in the Rio en Medio at 400 to 2200 m below the road.



NH4-N
2200
1200
800
400
1.00
0.80
0.60
0.40
020
mg/l
A
M
J
J
A
S
O
N
D
1977

Figure 11. Ammonium-Nitrogen concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.

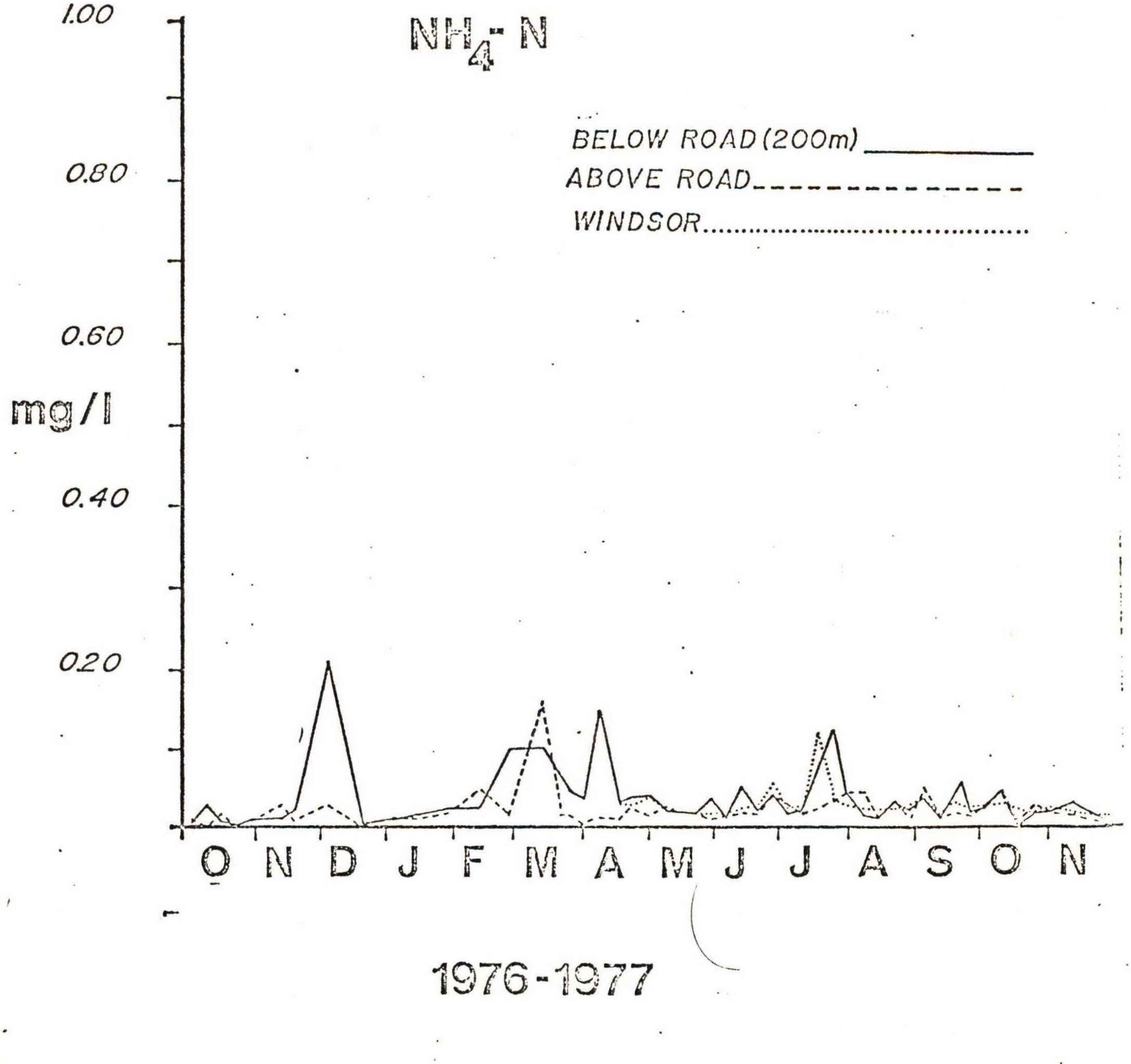
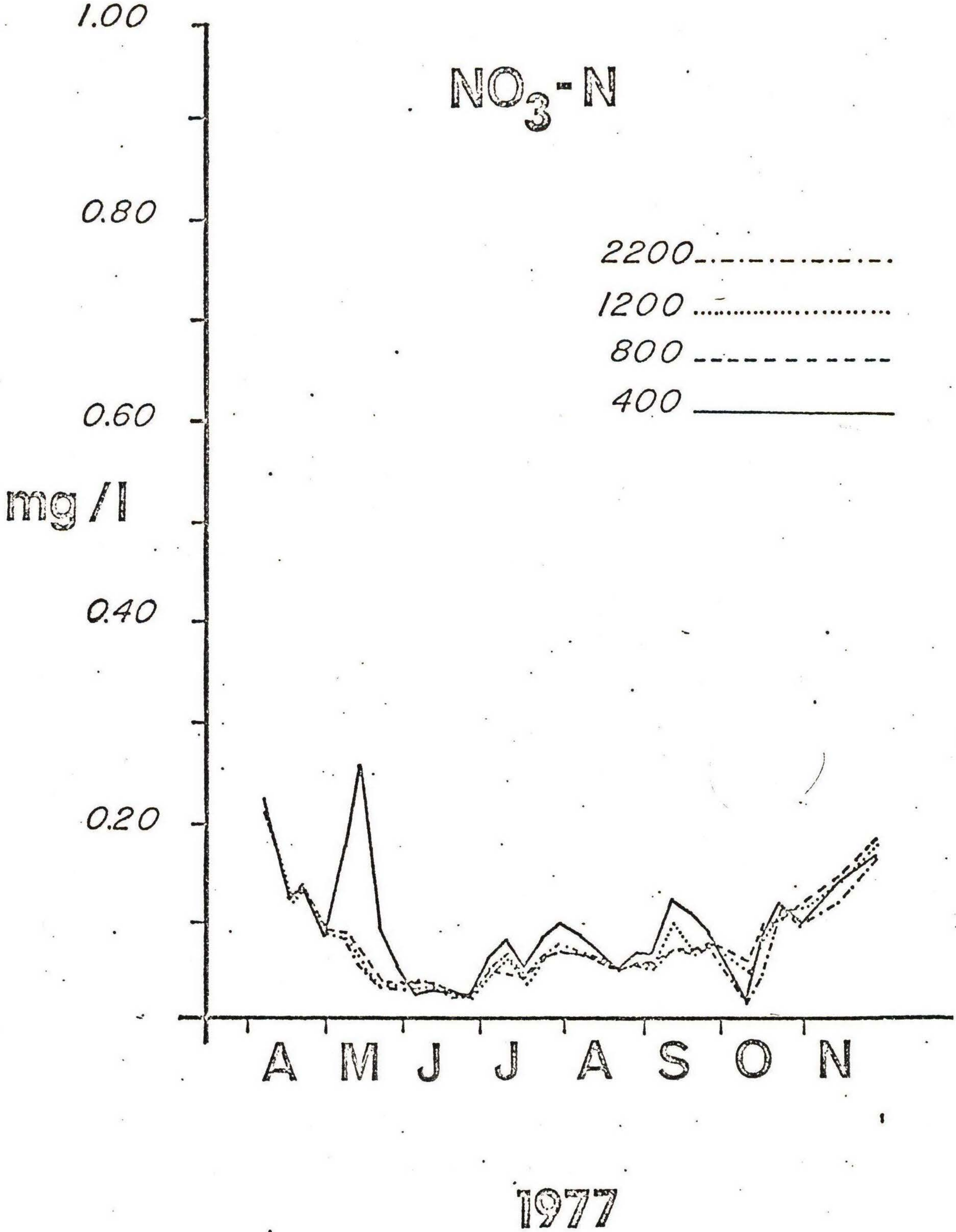
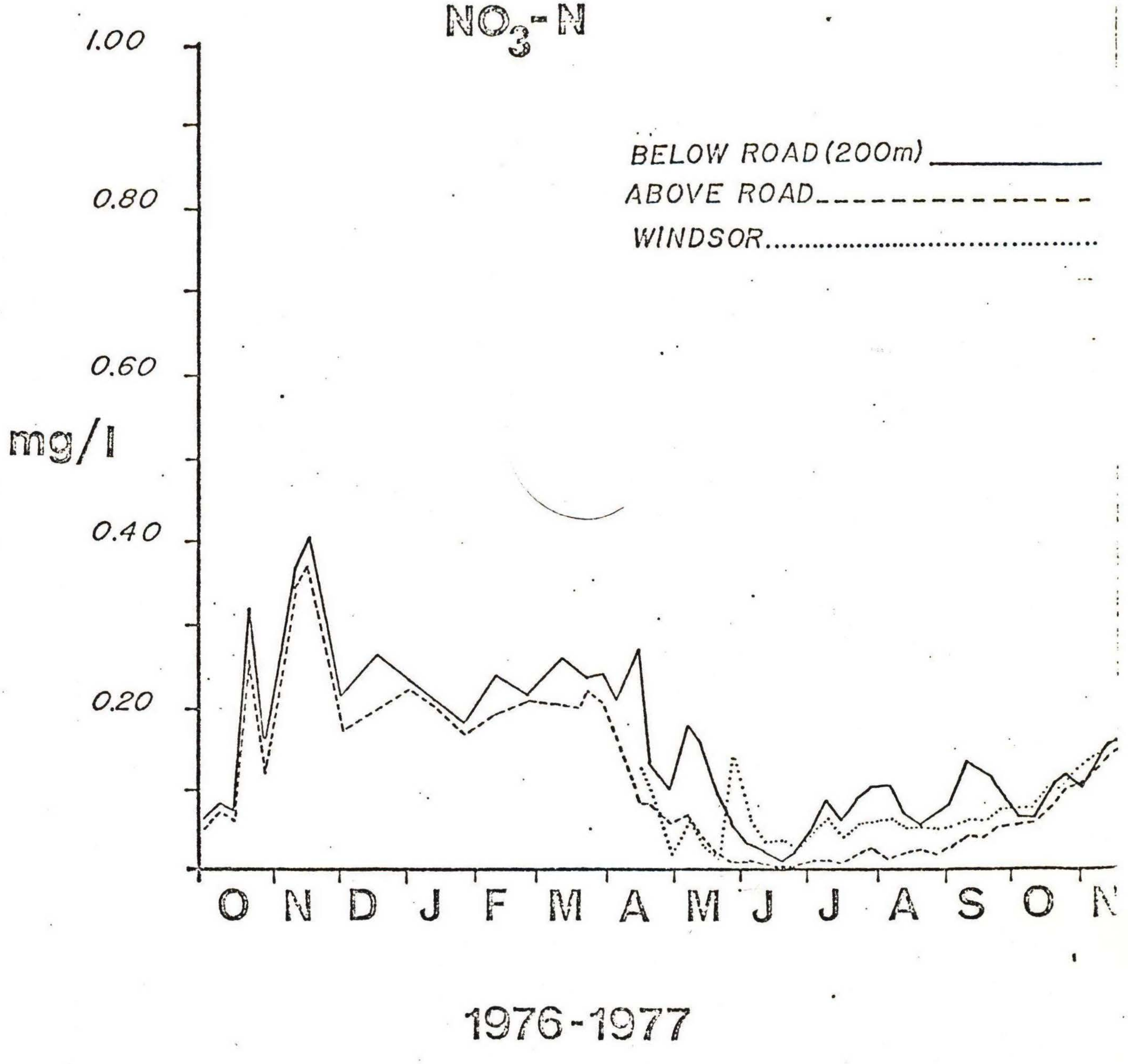

NH4- N
1.00
0.80
0.60
0.40
0.20
mg/l
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S O N
1976-1977

Figure 12. Nitrate-Nitrogen concentrations in the Rio en Medio at 400 to 2200 m below the road.



1.00
0.80
0.60
0.40
0.20
mg /l
NO_3-N
2200
1200
800
400
A
M
J
J
A
S
O
N
1977

Figure 13. Nitrate-Nitrogen concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.



NO3-N
1.00
0.80
0.60
0.40
0.20
mg/l
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
O N D J F M A M J J A S O N
1976-1977

Figure 14. Sediment concentrations in the Rio en Medio at 400 to 2200 m below the road.

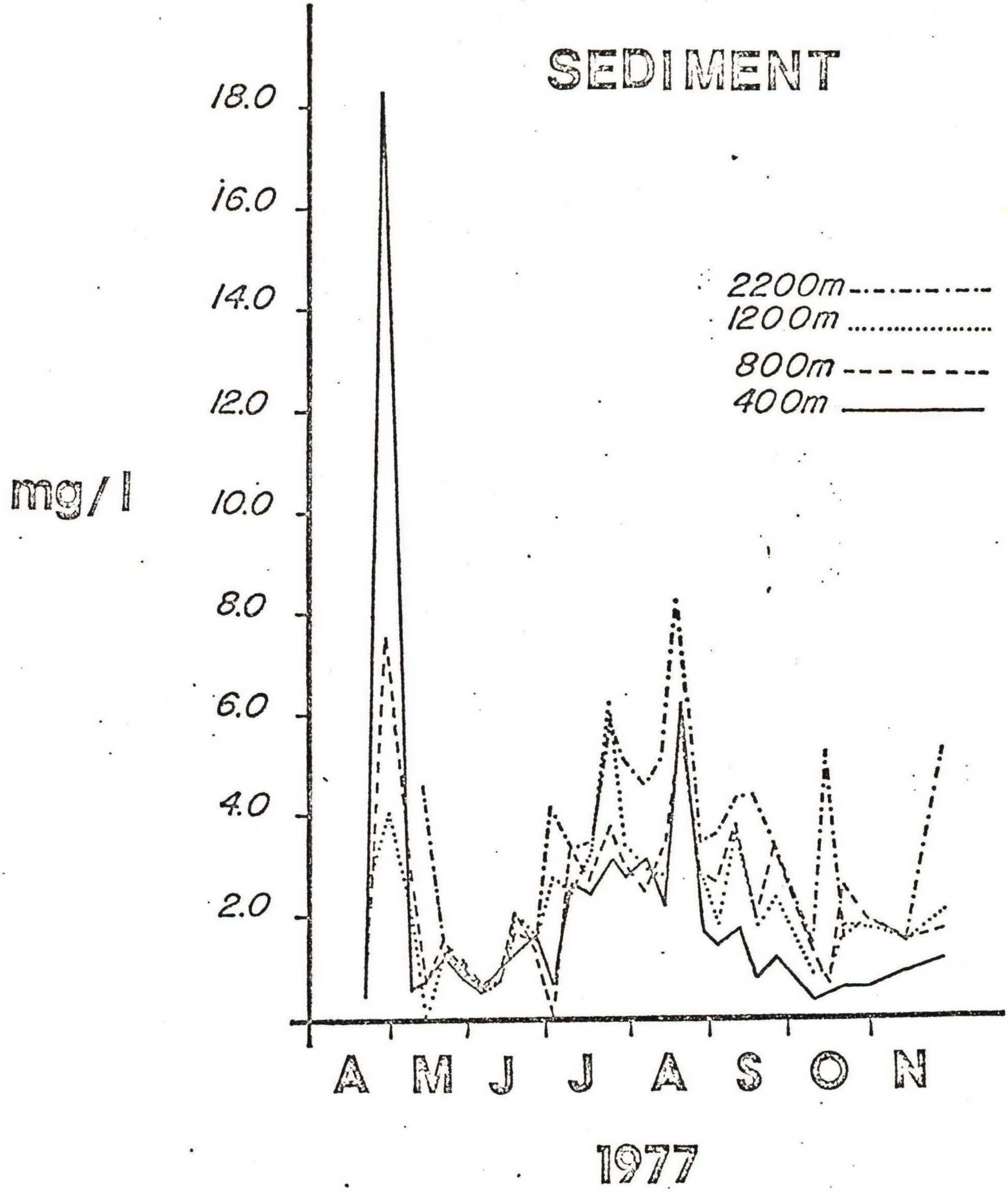
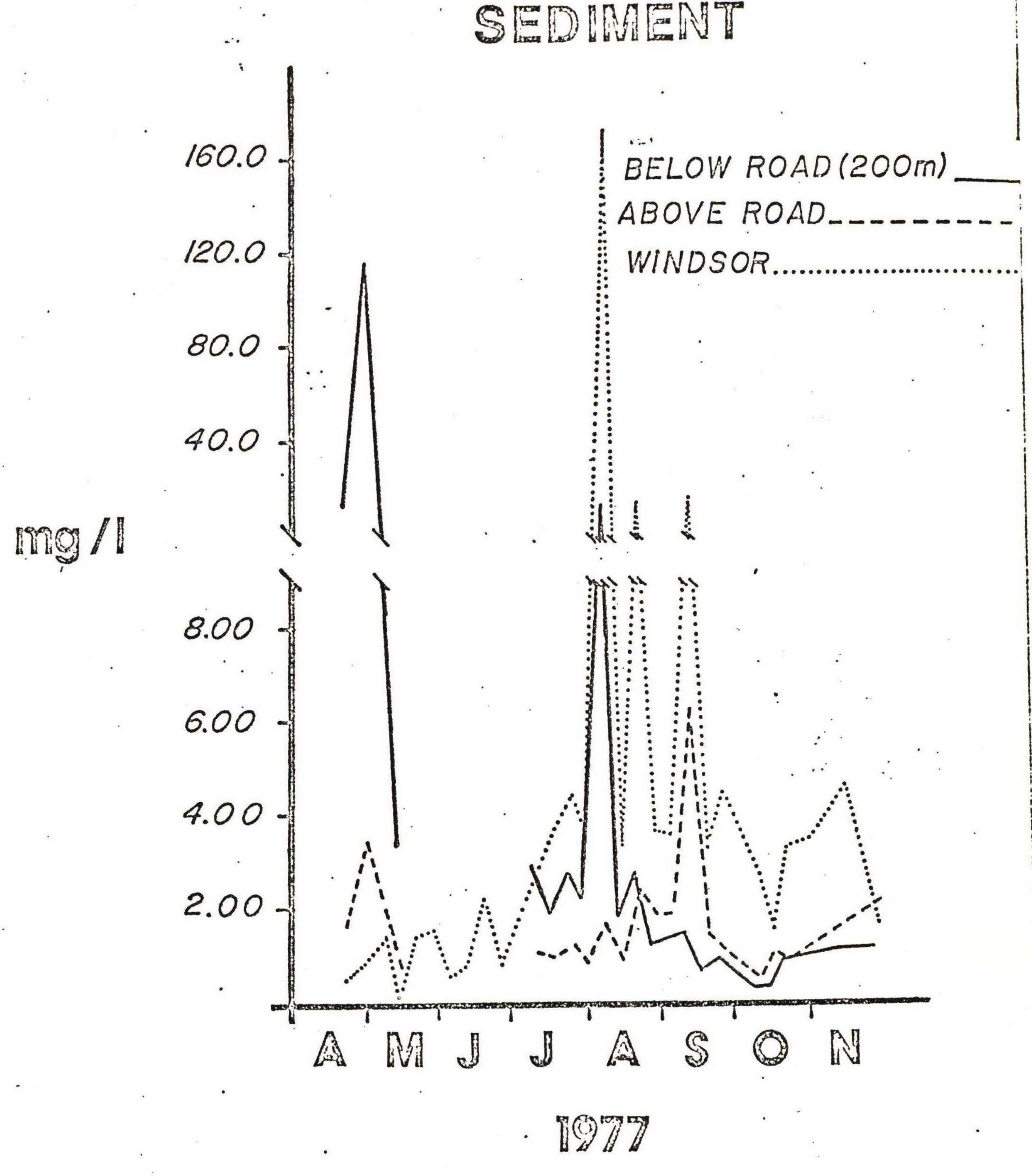
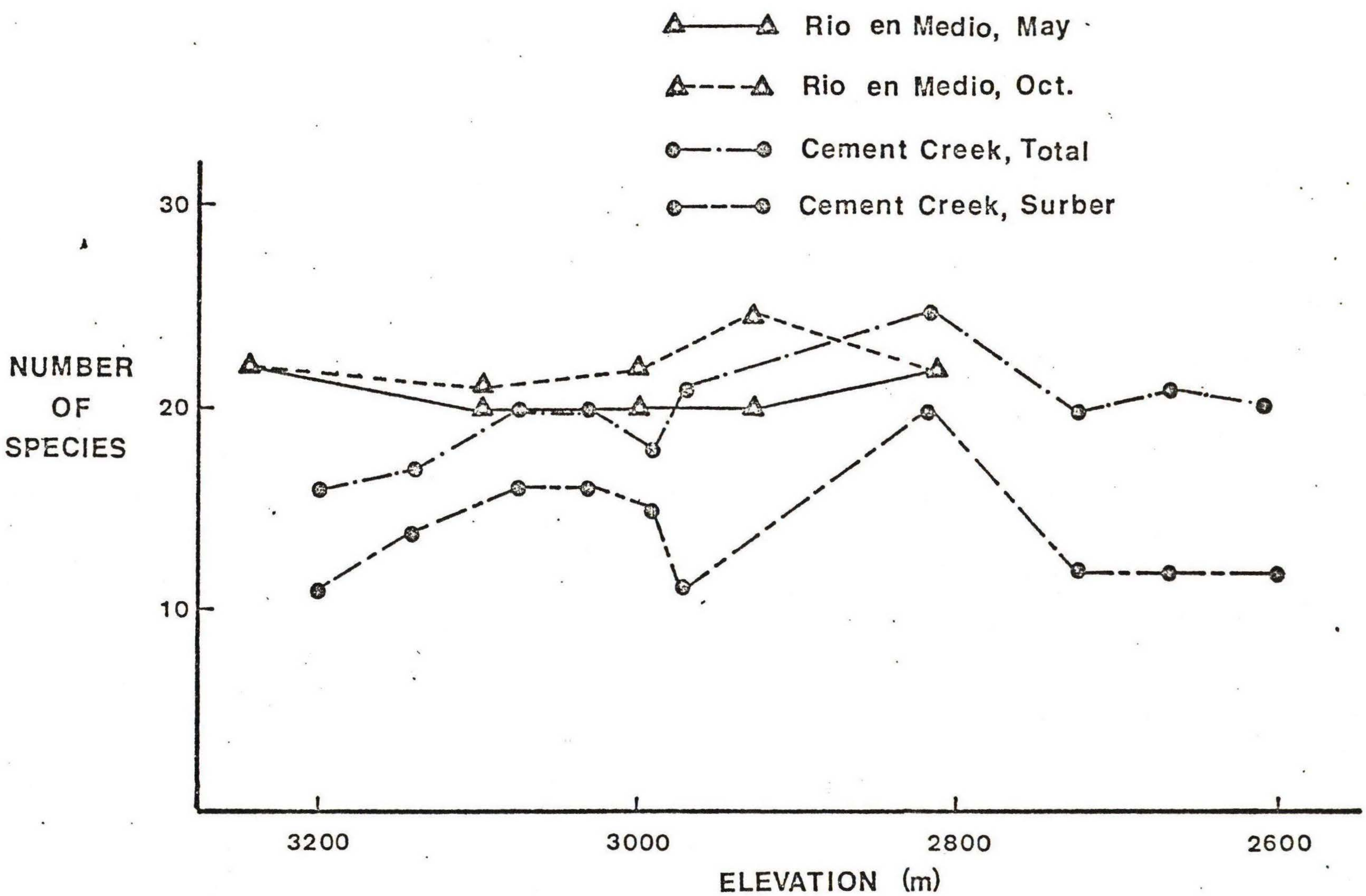

SEDIMENT
mg/l
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
2200m
1200m
800m
400m
A
M
J
J
A
S
O
N
1977

Figure 15. Sediment concentrations in the Rio en Medio above the road, 200 m below the road, and in Windsor Creek.



SEDIMENT
BELOW ROAD (200m)
ABOVE ROAD
WINDSOR
160.0
120.0
80.0
40.0
mg / l
8.00
6.00
4.00
2.00
A M J J A S O N
1977

Figure 16. Number of species collected in 12 Surber samples taken at each study site on the Rio en Medio compared with the number of species collected over a similar range of elevations in Cement Creek, Colorado (Allan 1975). Allan reported estimates of numbers of species resulting from 12 Surber samples and Surber samples plus qualitative collecting (Total).



Rio en Medio, May
Rio en Medio, Oct.
Cement Creek, Total
Cement Creek, Surber
30
20
10
NUMBER OF SPECIES
3200
3000
2800
2600
ELEVATION (m)

Figure 17. Species diversity, H', calculated from 12 Surber samples taken at each study site on the Rio en Medio and Cement Creek, Colorado (Allan 1975) over a similar range of elevations.

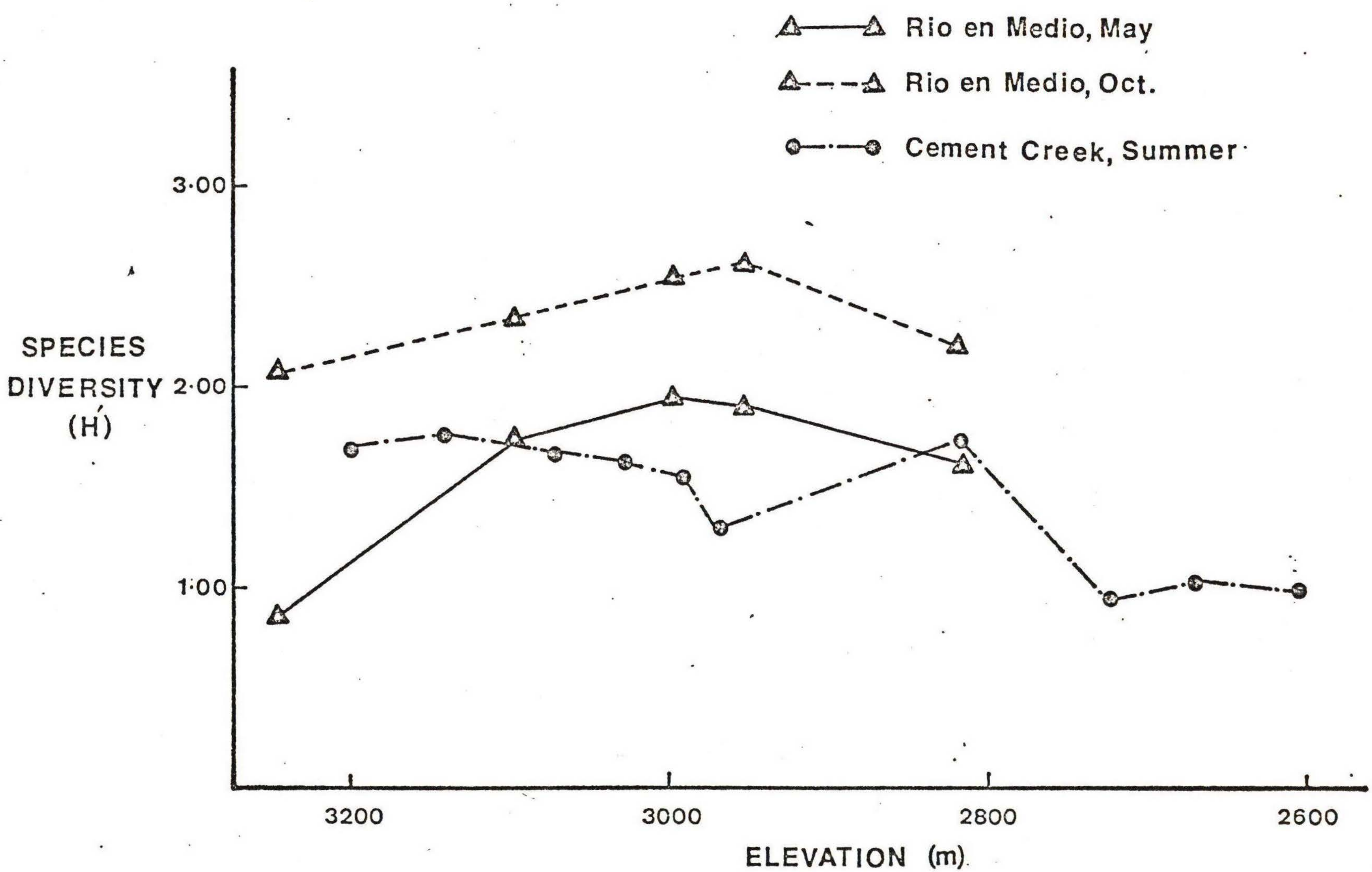
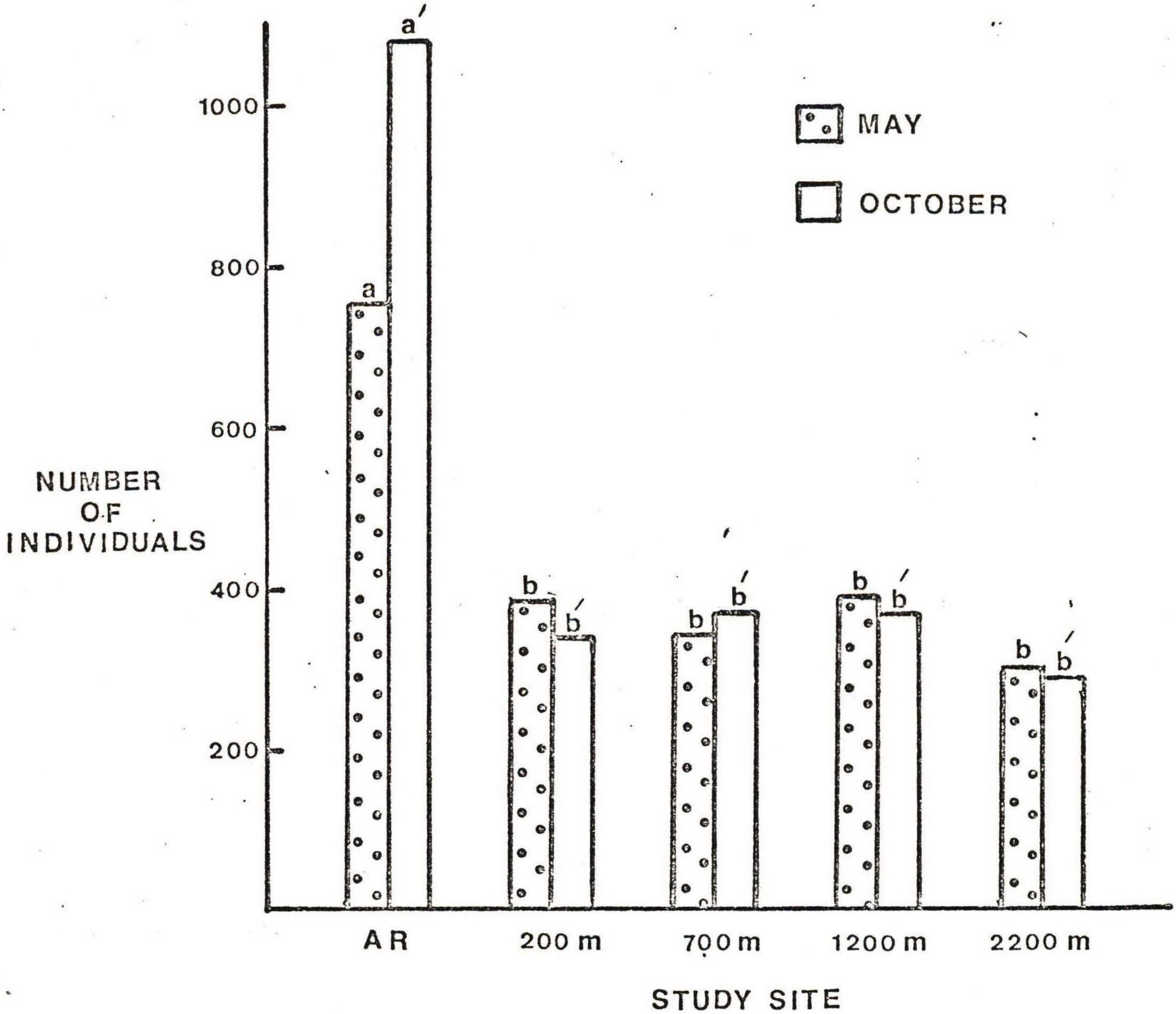
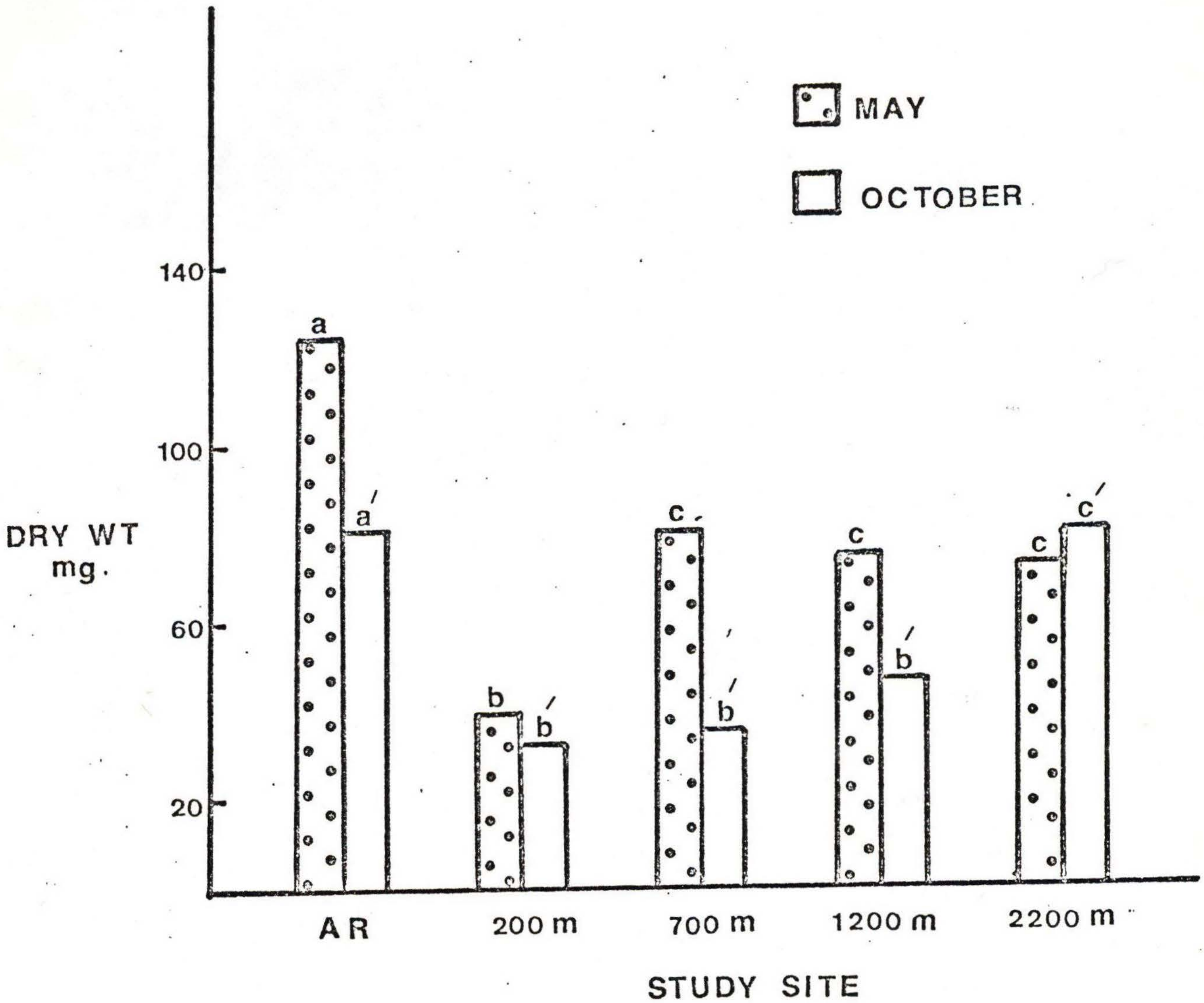

Rio en Medio, May
Rio en Medio, Oct.
Cement Creek, Summer
SPECIES DIVERSITY (H′)
3·00
2·00
1·00
3200
3000
2800
2600
ELEVATION (m)

Figure 18. Mean number of invertebrates per Surber sample (.093 m^2) at each study site on the Rio en Medio for May and October of 1977. Statistical comparisons were made within months only. Different letter superscripts indicate significant differences ($p < .05$).



MAY
OCTOBER
NUMBER OF INDIVIDUALS
1000
800
600
400
200
a'
a
b
b'
b
b'
b
b'
b
b'
AR
200 m
700 m
1200 m
2200 m
STUDY SITE

Figure 19. Mean dry weight of invertebrates per Surber sample (.093 m^2) at each study site on the Rio en Medio for May and October of 1977. Statistical comparisons were made within months only. Different letter superscripts indicate significant differences ($p < .05$).


MAY
OCTOBER
140
100
60
20
DRY WT
mg.
a
a'
b
b'
c
b'
c
b'
c
c'
AR
200 m
700 m
1200 m
2200 m
STUDY SITE